Vexless: A Serverless Vector Data Management System Using Cloud Functions (SIGMOD 2024)

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Presented by Patrick Lee for CSC 2233

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Designing data systems

- Focus so far on the internal mechanisms of how to make vector databases work
- Zoom out and take a look at the system design for deploying a vector database
- Our options:
    a. Manage our own virtual machines
    b. Have someone else manage the infrastructure
        - This is where cloud functions come in!

AzureVM

Azure Functions

Cloud functions

- FaaS (Functions as a Service)
- Submit code as a payload function
- All operational concerns hidden
- Charged only for function uptime + fixed function invocation overhead cost

Azure Functions

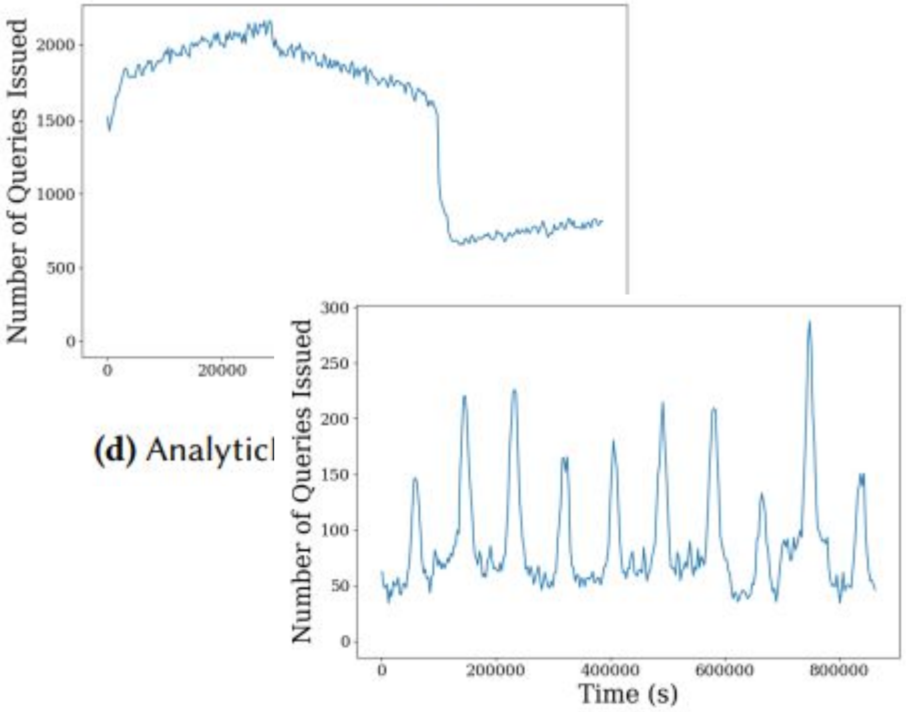
AWS Lambda

Google Cloud Functions

Virtual machines vs. Cloud functions

Functionality	**Virtual Machine**	**Cloud function**
Managed?	Yes	No (serverless)
Dedicated Server?	Yes	No
Stateful?	Yes	No(-ish)
Computational Limits?	Soft (based on machine)	Hard
Start-up time	Minutes	Seconds
Payment model	Rental	Pay-as-you-go
Price-per-unit (of compute)	Lower	Higher

Problem



(d) Analyticl

(e) Twitter Workload [75]

- ANN search
  - Find top-*k* results within *k* results returned by algorithm
- Cloud functions are more expensive than VMs
  - Unsuitable for dense and continuous workloads with long uptime
- Real-world applications of vector databases are sparse and bursty

RQ: Can we use cloud functions to build high-performance and cost-efficient vector databases?

Vexless: 3 Challenges and 3 Contributions

Challenge 1: Hard resource limits in cloud functions, more than one needed

Contribution: Even workload distribution via bespoke sharding algorithm

Challenge 2: Communication (latency) overheads

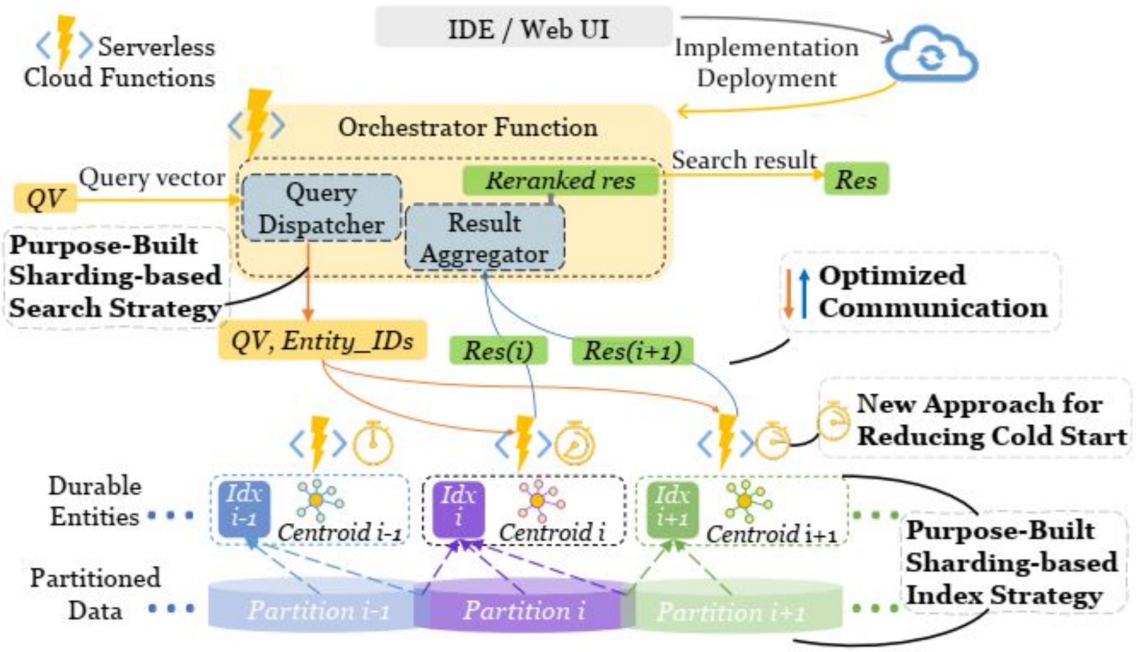
Contribution: Communication hub mechanism

~~Challenge 3: Cold starts~~

~~Contribution: Adaptive scheduling algorithm~~

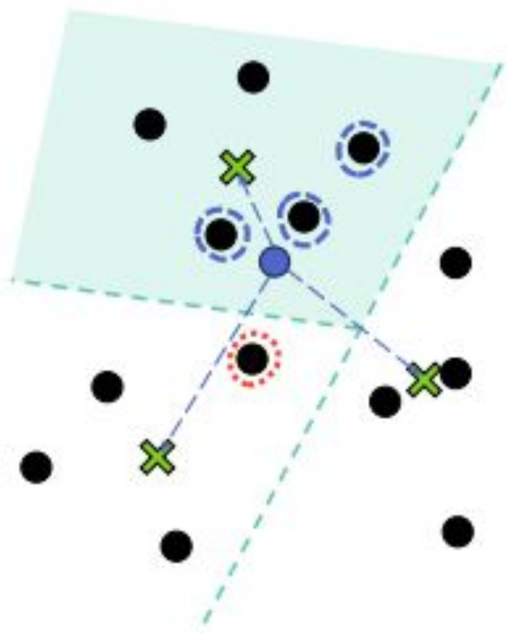
Main System Idea

- Use a distributed vector search, treating each cloud function as a computational unit
  - Sharding phase (partitioning)
  - Search Phase (Identify → Activate → Aggregate)



Naive Sharding Approaches

- Azure has a memory limit of 1.5 GB per cloud function
- Azure functions OOM at 3 million vectors
- How can we split up the database?
  - Uniform sharding
  - Cluster-based (k-means) sharding
  - Balanced k-means sharding



From Moshe Gabel CSC2233 Week 1 Week 1 Slides

Improved Sharding-based Index & Search Strategy

- Balanced K-means problem: Worse search efficiency
- Reason: Forcing boundary points to achieve balance
- Searching in incorrect clusters as a result
- Solution: **radius-threshold-based clustering**

Stage 2: Index Building

Initialization: For cluster c_i, initialize an empty index partition I_i. Set distance threshold T for redundancy indexing.
for each base vector v in D **do**
    Compute v's distances $\mathrm{d}(v, C_i)$ to centroids $C_1, C_2, \ldots, C_k$.
    Rank $\mathrm{d}(v, C_i)$.
    Include v in the index I_h corresponding to its centroid C_h.
    for each centroid C_i where $i \neq h$ **do**
        if $\mathrm{d}(v, C_i) < T$ **then**
            Add v to I_i.
        end if
    end for
end for

Improved Sharding-based Index & Search Strategy

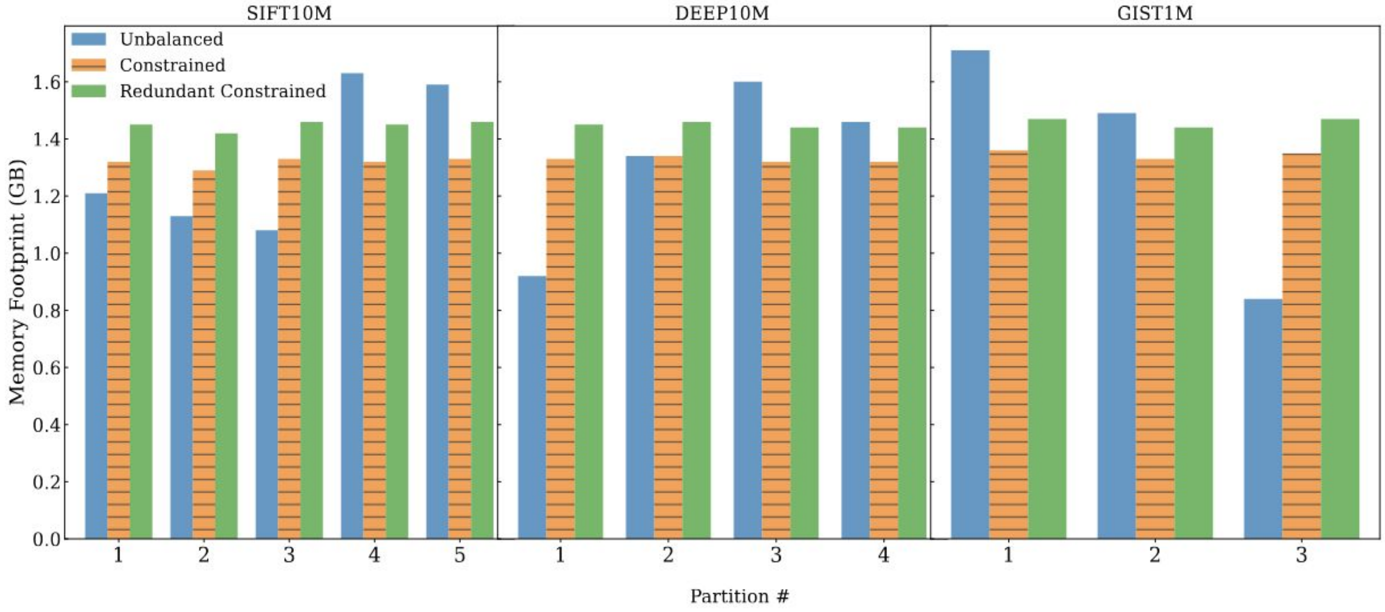
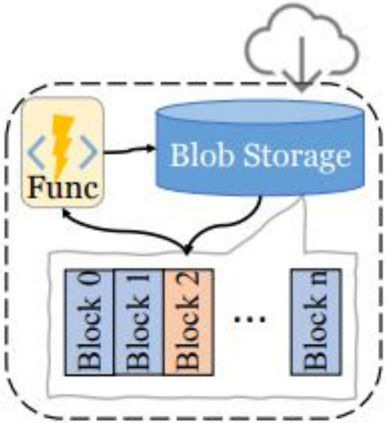


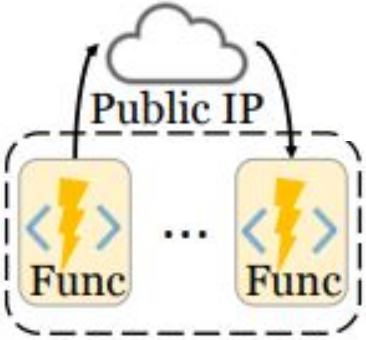
Fig. 3. Comparison of Vector Data Clustering Results using Different Unsupervised Clustering Algorithms

Naive Communication Mechanism

- Vector search requires low latency to function
- Need to communicate aggregate results between cloud functions
- Two choices:
    - Global (blob) storage
    - HTTP-based



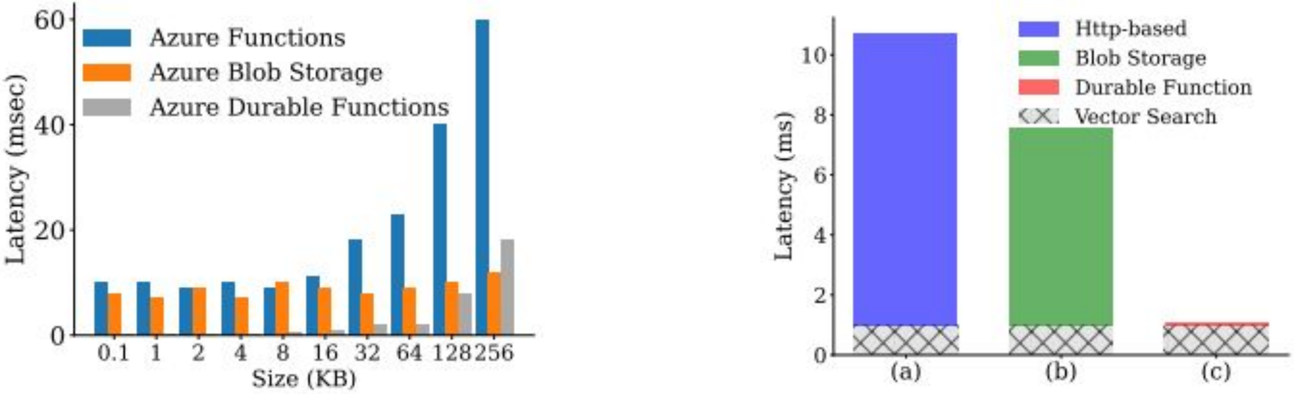
(b) Blob Storage



(a) HTTP-Based

Optimized Communication Mechanism

- Solution: Use Azure Durable functions as stateful orchestrators
- Can preserve states across multiple function invocations
- Avoid HTTP, exploit other communication channels (e.g. message passing via Azure Queue Storage

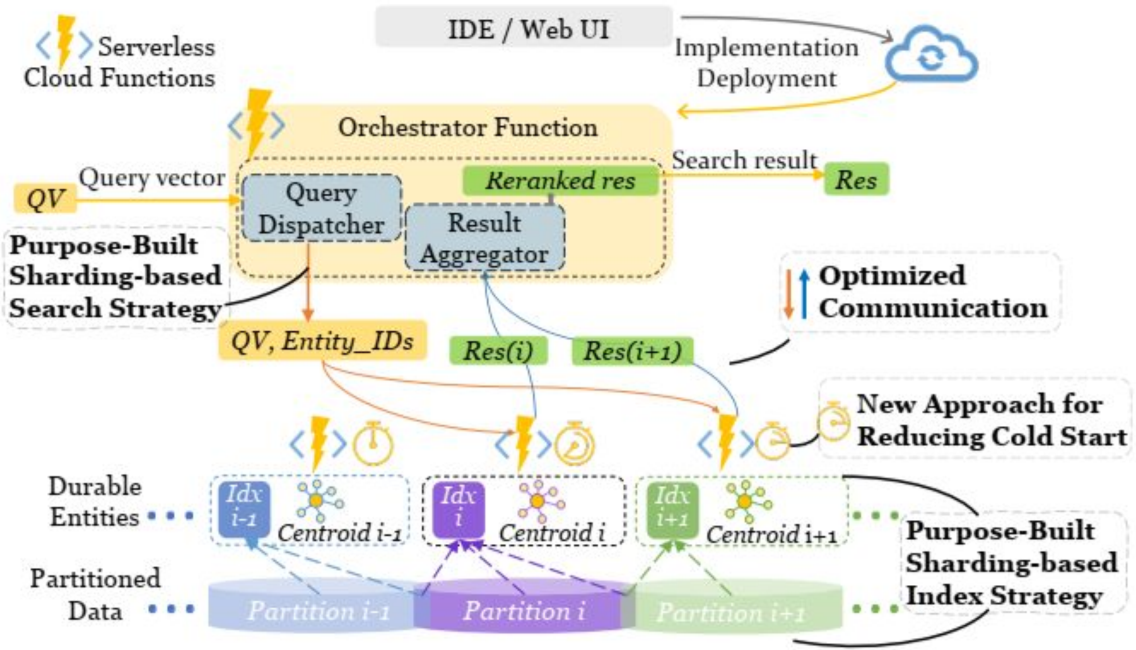


(a) Communication Overhead **(b)** Overhead with Vector Search

Fig. 4. Cloud Communication Overhead Comparison

Main System Idea

- Use a distributed vector search, treating each cloud function as a computational unit
  - Sharding
  - Communication hub



Experiment

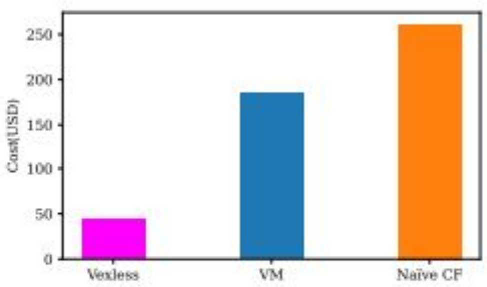
- Datasets: SIFT10M (*d=128)*, DEEP10M (*d=96*), GIST1M (*d=960*)
- Workloads: Sparse, burst, continuous, real-world
- Evaluation: Latency, accuracy (recall@10 default)
- Hardware: Azure VM F4 (8 GB RAM, 4 vCPUs)

Table 1. Datasets

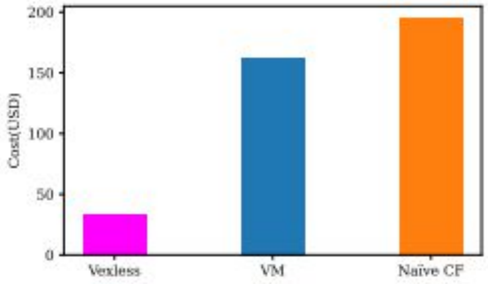
	SIFT10M	DEEP10M	GIST1M
# of Base Vectors	10,000,000	10,000,000	1,000,000
# of Query Vectors	10,000	10,000	1,000
Dimensionality	128	96	960
Data type	int32	float32	int32

Results (cost)

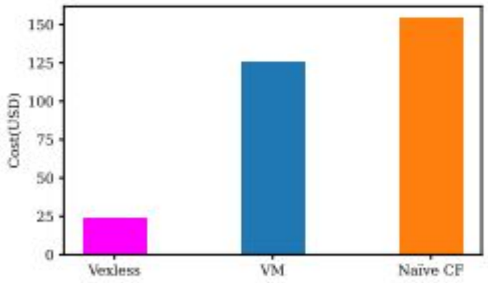
- Vexless can provide cost savings up to **5.3x** for VM-based solutions and nearly **6.5x** for naive cloud implementations



(a) SIFT10M: Monthly Cost, Sparse Queries

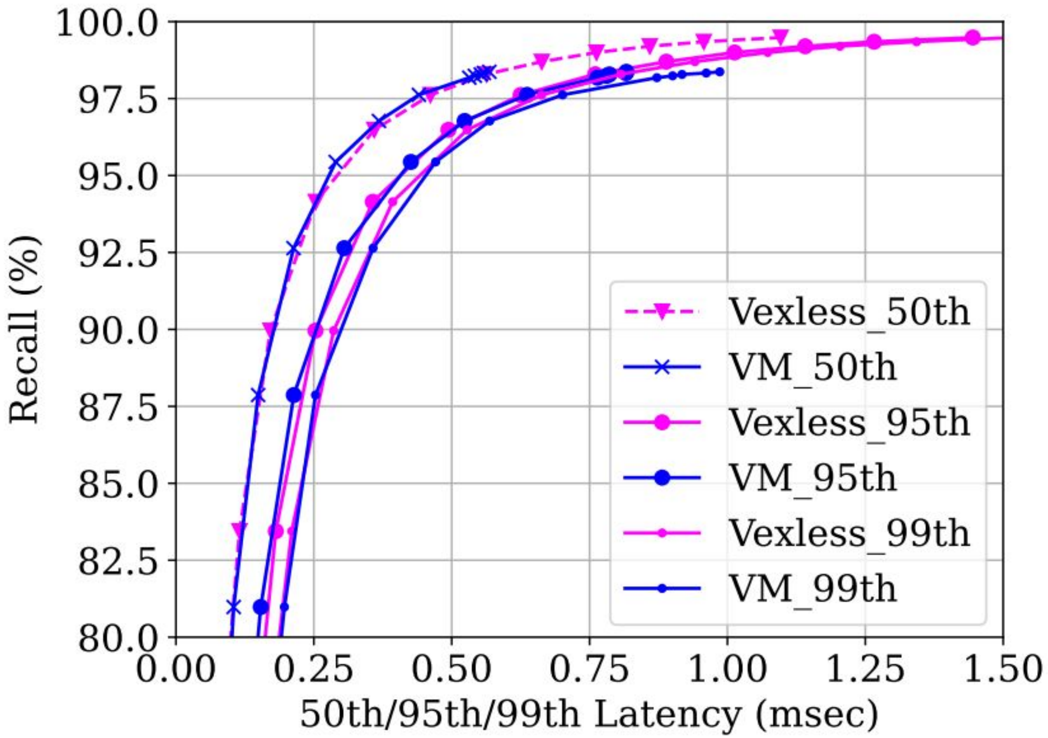


(d) DEEP10M: Monthly Cost, Sparse Queries



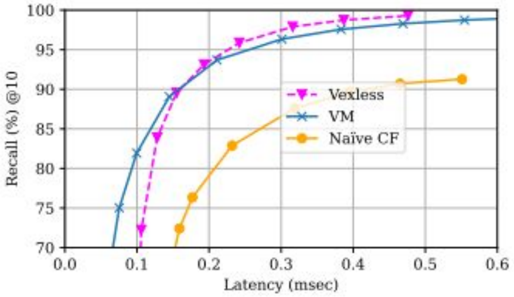
(g) GIST1M: Monthly Cost, Sparse Queries

Results (latency)

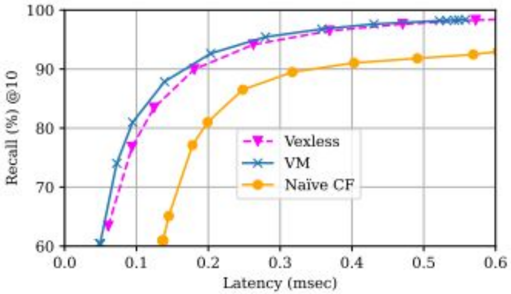


Results (recall)

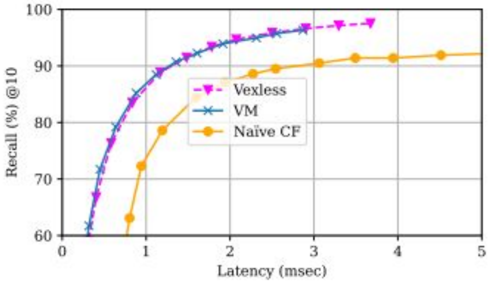
- Authors state *Vexless* offers best search performance across three different datasets



(c) SIFT10M: Search Recall@10 Performance



(f) DEEP10M: Search Recall@10 Performance



(i) GIST1M: Search Recall@10 Performance

Critical lens

After seeing all this, are you convinced *Vexless* is actually a good solution for deploying a vector database?

- Are there other ways of achieving cost savings?
- Is *Vexless* actually adhering to serverless principles?
- What are the maintenance/operational concerns?
- What about billion-point datasets necessitating multiple orchestrators?

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